positron issued from the β^+ emitters induced in the patient tissues along the beam path. These methods require being able to detect with a huge efficiency, and with a minimum dead time, these secondary particles emitted when the beam hits the patient.
The LAPD is similar to a conventional Positron Emission Tomography camera. The 511 keV γ are detected and the reconstructed line of responses allow to measure the β^+ activity distribution. Nevertheless, when trying to use γ from positron annihilations for the ballistic control in hadrontherapy, the large γ prompt background should be taken into account and properly rejected.
This detector is made of two half-rings of 120 channels each (figure 1).

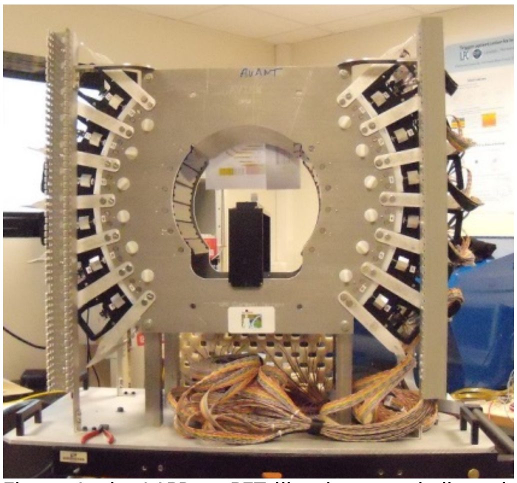

Figure 4: the LAPD, a PET-like detector dedicated to beam ballistic control in hadrontherapy.

Each channel consists of a 13*13*15 mm^3 LYSO crystal glued to a PMT. The PMT signal is sent to an Analog Sampling Module (ASM board). This VME 6U board is based on the DRS4 chip technology (Switch Capacitor Array) from the Paul Sherrer Institute and was specially designed for the LAPD detector. This board receives up to 24 differential analog input signals, with maximum amplitude of 600 mV, digitized by 12 bits - 33 MHz ADC. The sampling rate varies between 1 and 5 GHz, for a maximum buffer size of 1024 samples.
The first part of the talk is devoted to the description of the detector and its electronics. Then, we describe the various trigger strategy, and the on-going upgrade of the VME-based acquisition system to a µTCA-based technology. The selection of the coincident 511 keV γ is also discussed, and the reconstruction using an iterative MLEM algorithm is presented. In the last part of the talk, few results from an experiment with one third of the detector, using proton and carbon ion beams at the Heidelberg Ion-Beam Therapy Center in 2014, are also described, and the Coincidence Resolution Time and energy resolution are given. First reconstruction results, obtained with a phantom filled with a high intensity FDG source at the cancer research center of Clermont-Ferrand in 2015 are also shown.
This detector is now characterized, and will be installed at the Lacassagne hadrontherapy center (Nice, France), on the 65 MeV line (Medicyc) in December 2015 first, and on the future 230 MeV line (S2C2 from IBA) in 2016. The capability of this detector and its associated electronics to measure the ballistic of the proton beam in real clinical conditions with a sufficient precision will be evaluated.

Keywords: hadrontherapy, PET, beam ballistic control

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147
Visualization of target inhomogeneities in carbon ion radiotherapy using nuclear fragments

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Purpose: Ion beams are used for highly precise radiotherapy, making an accurate dose deposition in tissue crucial. However, this accuracy can be compromised by unpredictable changes of the patient. Therefore an online monitoring of the beam within the patient is of large interest. The main challenge is given by stopping of the entire beam inside of the patient. Our group investigates the possibility to collect and reconstruct the information about the beam extension in the patient by detecting light ions emitted from the irradiated object, suggested in [1]. Exploiting the directions of secondary ions measured, a method for visualization and quantification of the carbon ion beam profile in a homogeneous phantom was published in [2]. In this contribution, the capability of the method to detect inhomogeneities in otherwise homogeneous phantoms is presented.
Materials & methods: The experiments were performed at the Heidelberg Ion Beam Therapy Center (HIT) in Germany. Narrow carbon ion beams of therapy-relevant energies, were directed onto homogneneous plastic phantoms with a typical head size. Secondary ions emerging from the phantom during the irradiation, were detected by a Timepix detector [3] developed by the Medipix Collaboration at CERN. A multilayered detector, consisting of 3 parallel Timepix detectors, was used to measure their tracks in 3D. The track distributions acquired with a full phantom were compared with cases when parts of the phantom were missing at several positions, simulating cavities in the body.
Results: It was found that exploiting the information carried by secondary ions enables to visualize cavities in the irradiated volume at different positions of the Bragg curve. The method was found to be sensitive also to cavities situated behind the Bragg peak (in the fragment tail). Moreover, a three-dimensional image reconstruction based on maximum likelihood expectation maximization (MLEM) exploiting the measured secondary particle tracks was developed. In the resulting images, air cavities and inhomogeneities with density differences down to 0.3 g cm^{-3} to the surrounding material are clearly visualized for the first time.
Conclusions: Our experimental results demonstrate that this novel imaging modality enables clear visualization of down to 1 cm-sized air cavities in head-sized phantoms, under clinical irradiation conditions. Therefore we conclude that secondary ions, being a by-product of the irradiation, are an attractive source of information on the actual beam extension in the irradiated body.
Keywords: carbon ion radiotherpy, in-vivo beam monitoring, secondary charged particles

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148
The effect of fractionated administration of thalidomide at γ-ray irradiation on tumor response and lung metastasis

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